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Measurements of the integrated solar flux in the calcium K-line mode at Sacramento Peak are compared to those made at Kitt Peak. The measurements span about 2 solar cycles. The solar measurements are compared with similar measurements made for Solar-l.Ke stars. We find that compared to other solar-l.Ke stars, that the sun is in a very active cycling state. Stars appear to spend about one-third of their lifetime in non-cycling states such as the Maunder minimum which occured in the 17th century.

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SOLAR CaII MEASUREMENTS AND ACTIVITY CYCLES IN SOLAR-TYPE STARS

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1. THE SOLAR MEASUREMENTS

Measurement of the CaII K index began at the NSO early in solar cycle 21, in 1974, and continues to the present time. These measurements are relative spectral irradiances from the full solar disk. Two experiments are run independently, at Sacramento Peak by Steve Keil and at Kitt Peak by Bill Livingston. The observing and data reduction techniques are very similar; the principal difference lies in the observing cadence. Keil runs a daily measurement program, while Livingston observes on four consecutive days each month.

Figure 1 shows the irradiance profile for the K line measured at Kitt Peak on 5 May 1991. The K index, denoted by K1A, is obtained by integrating the central one angstrom in the line core. The intensity scale for the final calculation is relative to a reference continuum defined by measurements at 4020 and 3875A, which are intensity points close to a photospheric continuum. Note that the intensity scale in Figure 1 is relative to the maximum value near +3.5A. For each day's observation, the measured spectra are reduced to an index as well as to other parameters describing line asymmetry, strength, position, etc.

2. COMPARISON OF THE SAC PEAK AND KITT PEAK DATA

Figures 2 and 3 are plots of the measurements, from the beginning of the program to 1990 and 1991, for Sac Peak and Kitt Peak, respectively. We achieved a daily cadence regularly at Sac Peak starting in 1984, and these data are very good from this point forward in time. Prior to that time, the correlation with the Kitt Peak data appears to vary with time. For purposes of comparison between the two data sets, only Sac Peak data from 1984 will be considered, but both data sets show the basic solar cycle of chromospheric activity for cycle 21 and cycle 22.

Only 137 of these measurements were made on the same day, and these like data points are shown in Figure 4 as a regression between the two sets of data. The linear regression between the two variables yields the transformation equation:

$$K1A_{kp} = -0.0105 + 1.103\ K1A_{sp},$$

which we use to transform between the two measurement scales. $K1A_{kp}$ denotes the Kitt Peak measurements, and $K1A_{sp}$ are those from Kiel's program at Sacramento Peak. The correlation coefficient for these data is .94. The standard deviation of either data set about the regression curve is .005A, or approximately 5% of typical values of the index in the range from .08 to .11A.

This level of agreement between these measurements of the same line on the same day is not entirely satisfactory to us, and the sources of the differences have not been determined. The differences are random and, therefore, are related to noise sources such as scintillation and sky transparency changes.

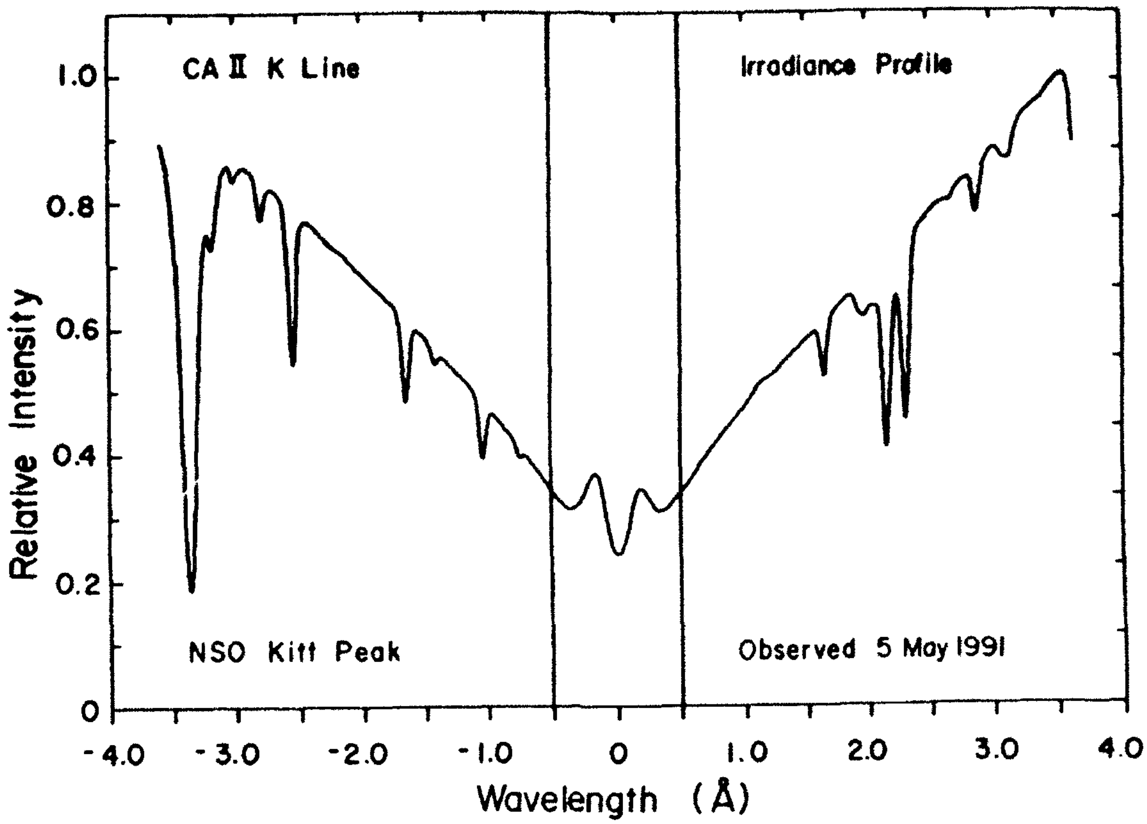

Figure 1. The CaII K irradiance profile measured at Kitt Peak on 5 May 1991.

3. THE RELATIONSHIP TO STELLAR MEASUREMENTS

Baliunas and Jastrow (1990) summarize the results of the Mt. Wilson measurement program begun by O. C. Wilson in 1967 to observe chromospheric variability in stars other than the Sun. The histogram at the top of Figure 5 shows the distribution of stellar K index measurements found by Baliunas. The important feature of this distribution is the discovery that "non-cycling" stars make up the narrow distribution at small values of the index, while the cycling stars define the broader distribution that extends to about $<hk> = .2$.

We are interested in how the solar data relate to this larger body of information because the stellar sample includes solar-type stars that do not cycle. The Mt. Wilson and NSO measurements are not directly comparable because both the H and K lines are measured in the stellar program, and the reference continua are not the same. However, Baliunas and her colleagues made a careful analysis of the two types of measurement. Lean, Livingston, Skumanich, and White (1991) made a separate analysis, and the combination of the two results yields the following transformation equation between the Mt. Wilson and Kitt Peak measurements:

$$<hk>_{stellar} = 0.04 + 1.54\ K1A_{solar}.$$

The solar observations shown in Figures 3 and 4 yield the solar distribution functions shown in Figure 5 (middle and bottom histograms). This immediately shows that the solar variation falls at the upper bound of Baliunas' stellar distribution, i.e., the Sun is a long way from the non-cycling state at the present time.

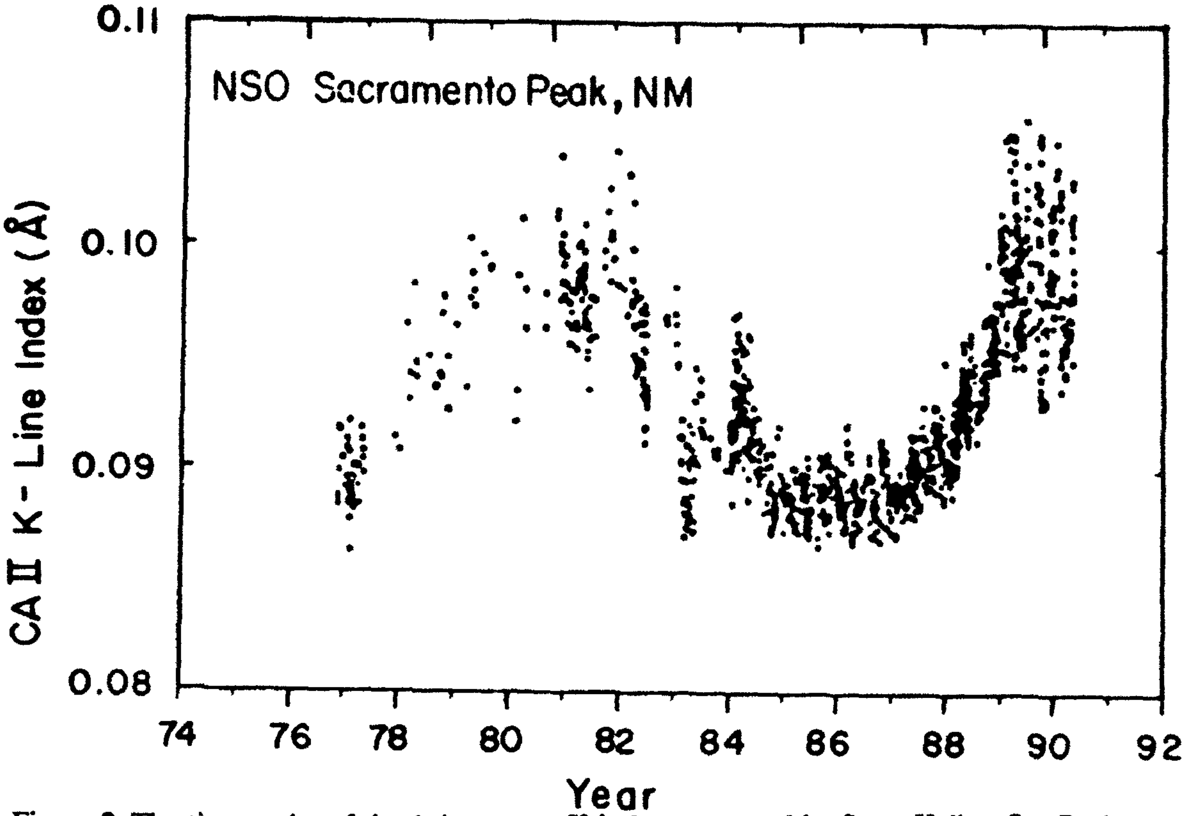

Figure 2. The time series of the 1 Angstrom K index measured by Steve Keil at Sac Peak Daily cadence.

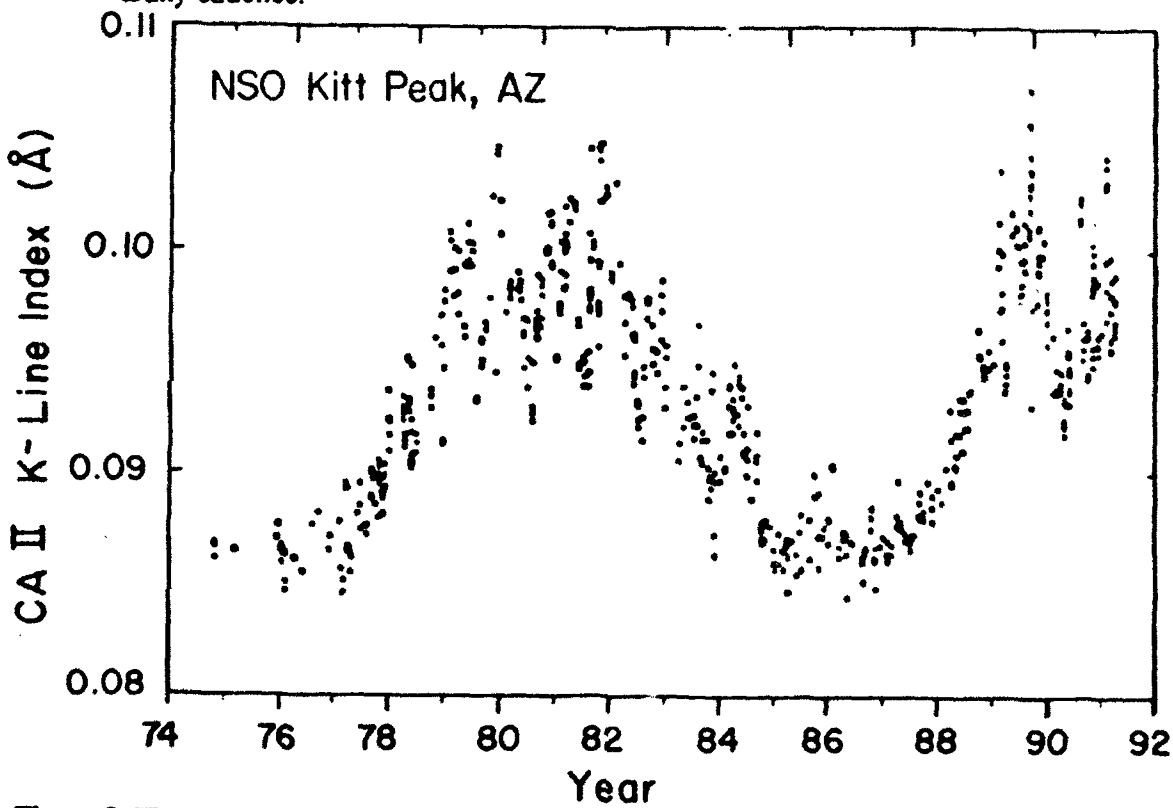

Figure 3. The time series of the 1 Angstrom K index measured by Bill Livingston at Kitt Peak. Monthly cadence.

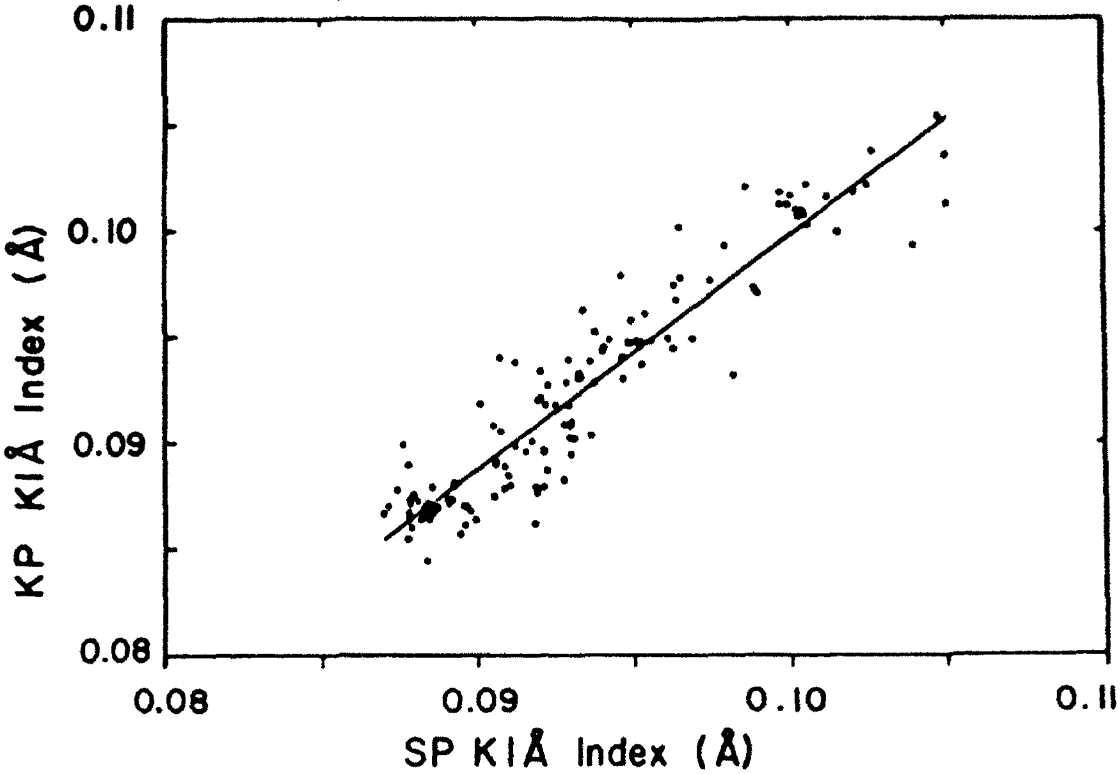

Figure 4. Regression plot of Kitt Peak measurements vs. Sac Peak measurements from 1984–1990.

Baliunas and Jastrow (1990) suggest that the non-cycling stars in their sample are in the "Maunder minimum" state, assumed for the Sun in the 17th century. In other words, these stars have no sunspots and, presumably, no magnetic activity. Lean, et al. (1991) examined the possibility of a "non-cycling" state for the Sun, and concluded that 1) absence of magnetic activity is not sufficient to decrease the brightness of the UV spectrum to levels required for the non-cycling stars, and 2) in addition to eliminating magnetic activity, we also have to decrease the emission from the intercell regions not associated with activity.

4. IMPLICATIONS FOR SPECTRAL VARIABILITY OF THE SUN

The implication of this research to understand the Sun's place in a larger body of stars is that the Maunder Minimum phenomenon is not uncommon, i.e., it occurs in one third of the Baliunas-Jastrow sample. Such an event causes a large decrease in the EUV and UV output of the Sun as well as a decrease in the total irradiance (.3% in the solar case, see Lean, et al., 1991).

On average, then, such decreases occur one-third of the time for a solar-type star. Study of the radiocarbon record (see Damon and Sonnett 1991) shows large variability in both the occurrence and duration of periods similar to the Maunder minimum, but three periodicities persist in the radiocarbon record: 2250, 208, and 88 years. A deterministic model of solar variability given by Damon and Jirikowic (1991) based on this periodic structure suggests that another Maunder minimum is not imminent.

Progress in understanding the past and future behaviour of the Sun will continue to come from sound physical measurements of the radiative output of the Sun and other stars made

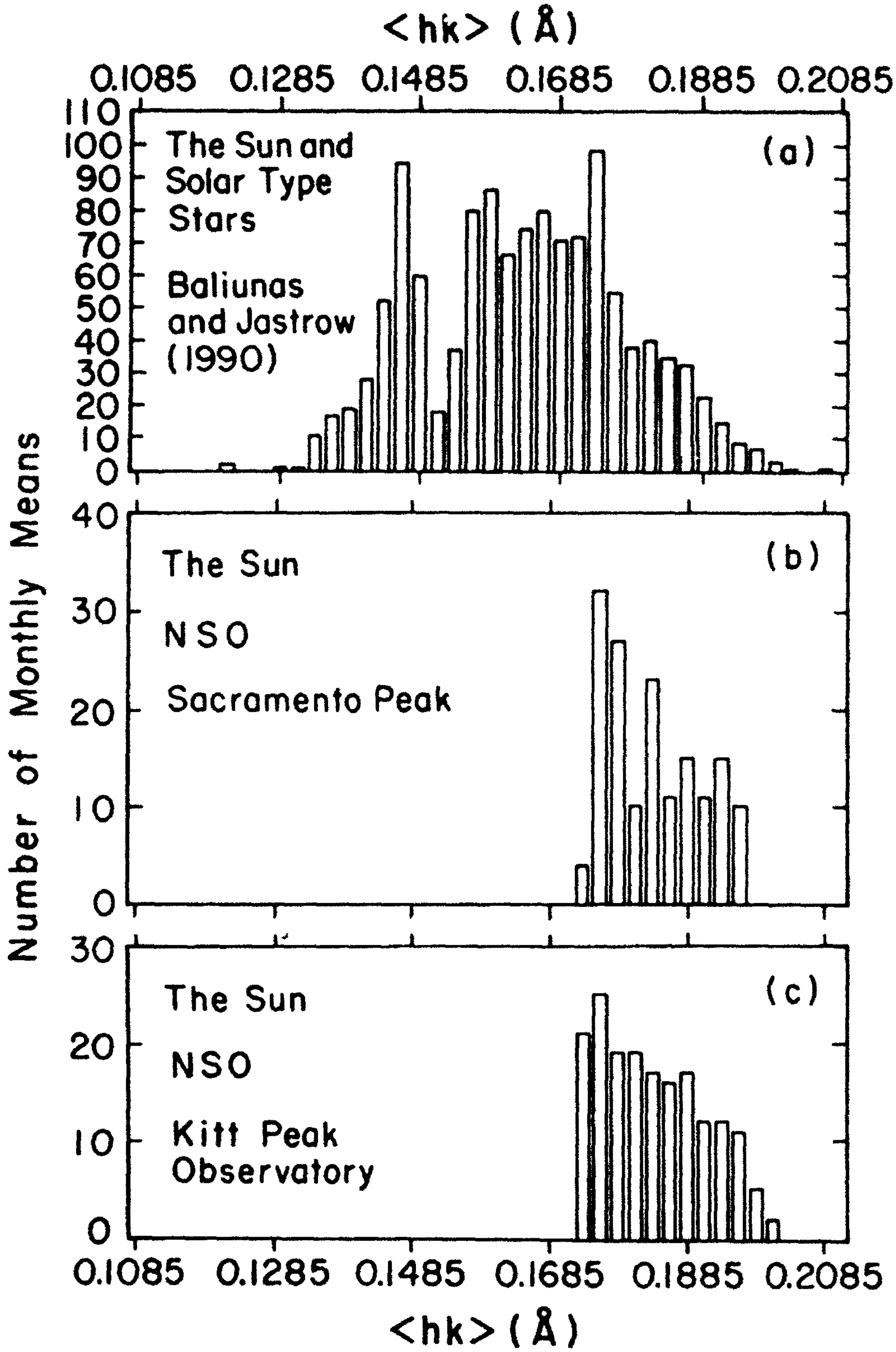

Figure 5. Top: reproduction of the Baliuinas-Jastrow distribution of the Mt. Wilson HK index for solar-type stars; middle: distribution of monthly means of the K index measurements (K1A) from Sac Peak; bottom: distribution of monthly means of the K index measurements (K1A) from Kitt Peak.

over solar cycle time scales. Indices such as the K index and the HeI 10830 index continue to stand as valuable measures of solar output variation and its relationship to solar surface structure.

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5. REFERENCES

Baliuinas, S. and Jastrow, R., *Nature*, **348**, 520–523, 1990.

Lean, J., Livingston, W., Skumanich, A., and White, O., *Nature* (in press), 1991.

Damon, P. E. and Sonnett, C. P., "Solar and Terrestrial Components of the Atmospheric 14C Variation Spectrum," in *The Sun in Time*, eds: Sonnet, C. P. Giampapa, M. S., Matthews, M. S., Univ. of Arizona Press, Tucson, AZ, (in press), 1991.

Damon, P. E., and Jirikowic, J. L., *Solar Forcing of Global Climate Change*, (in press), 1991.